NATIONAL RENEWABLE ENERGY LABORATORY

System Advisor Model (SAM)

SAM Virtual Conference 2015

Modelling a competitive CSP plant in Brazil: the role of biomass hybridization.

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1. Introduction

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ANÁLISE DO USO DE GÁS NATURAL NA HIBRIDIZAÇÃO DE PLANTAS TERMOSOLARES (CSP) NA BACIA DO SÃO FRANCISCO (BA)

Diego C. Malagueta[1], Rafael Soria [2], Alexandre S. Szklo[3], Ricardo M. Dutra[4], Roberto Schaeffer[5]

Energy Policy 59 (2013) 198–212

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Energy Policy

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Assessing incentive policies for integrating centralized solar power generation in the Brazilian electric power system

Diego Malagueta [a,*], Alexandre Szklo [a], Bruno Soares Moreira Cesar Borba [b], Rafael Soria [a], Raymundo

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Potential and impacts of Concentrated Solar Power (CSP) integration in the Brazilian electric power system

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Hybrid concentrated solar power (CSP)–biomass plants in a semiarid region: A strategy for CSP deployment in Brazil

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1. Introduction

CSP potential in Brazil’s Northeast

Technical CSP potential in Brazil

- Area: 97,000 km^2 of regions with DNI > 6 kWh/m^2/day (Soria, 2011)
- Potential: 203 GW, for CSP – PT with 6h TES; 43% in NE region (Bahia) (Burgi, 2013)
- No commercial power plants in operation or contracted.

CSP economic competitiveness: previous simulations

LCOE (cents USD/kWh)	Details	Reference
30.85	100 MWe, CSP-PT, 6h TES, alternative scenario, @Bahia	Malagueta et al. 2013, 2014
19.45	100 MWe, CSP-PT, 12h TES, alternative scenario, @Bahia after 2030	Malagueta et al. 2013, 2014
21.60	100 MWe, CSP-PT, NG hybridization, FFF of 25%, @São Francisco	Malagueta et al. 2012
19.72	100 MWe, CSP-PT, sugarcane bagasse hybridization, BFF of 25%, @Campo Grande	Soria 2011

Brazilian power sector – results from auctions

LCOE (cents USD/kWh)	Details	Reference
5.91	Wind power, centralized generation, @NE, SE and S regions	LEN 19 Auction, June 2014
5,89	Wind power, centralized generation, @NE, SE and S regions	3 LFA , 25 April 2015
10.19	PV power, centralized generation, @NE region	Pernambuco State Auction, December 2013
9.03	Biomass, centralized generation, @ NE region	LEN 21 Auction A-5, 30th April 2015

Concentration of biomass in the northeast region

- Peculiarities of the northeastern semiarid region: *caatinga* and *cerrado* ecosystems can provide large amount of bioenergy, including **jurema-preta** (*Mimosa tenuiflora).*

Source: Fazenda União

- Objectives:
  - To evaluate the economic feasibility of biomass-hybrid CSP plants that use jurema-preta wood.
  - Identify a specific path for Brazil in terms of CSP energy deployment.
  - Propose an industrial policy to develop a Brazilian CSP industry in NE region.

2. Methodology and data

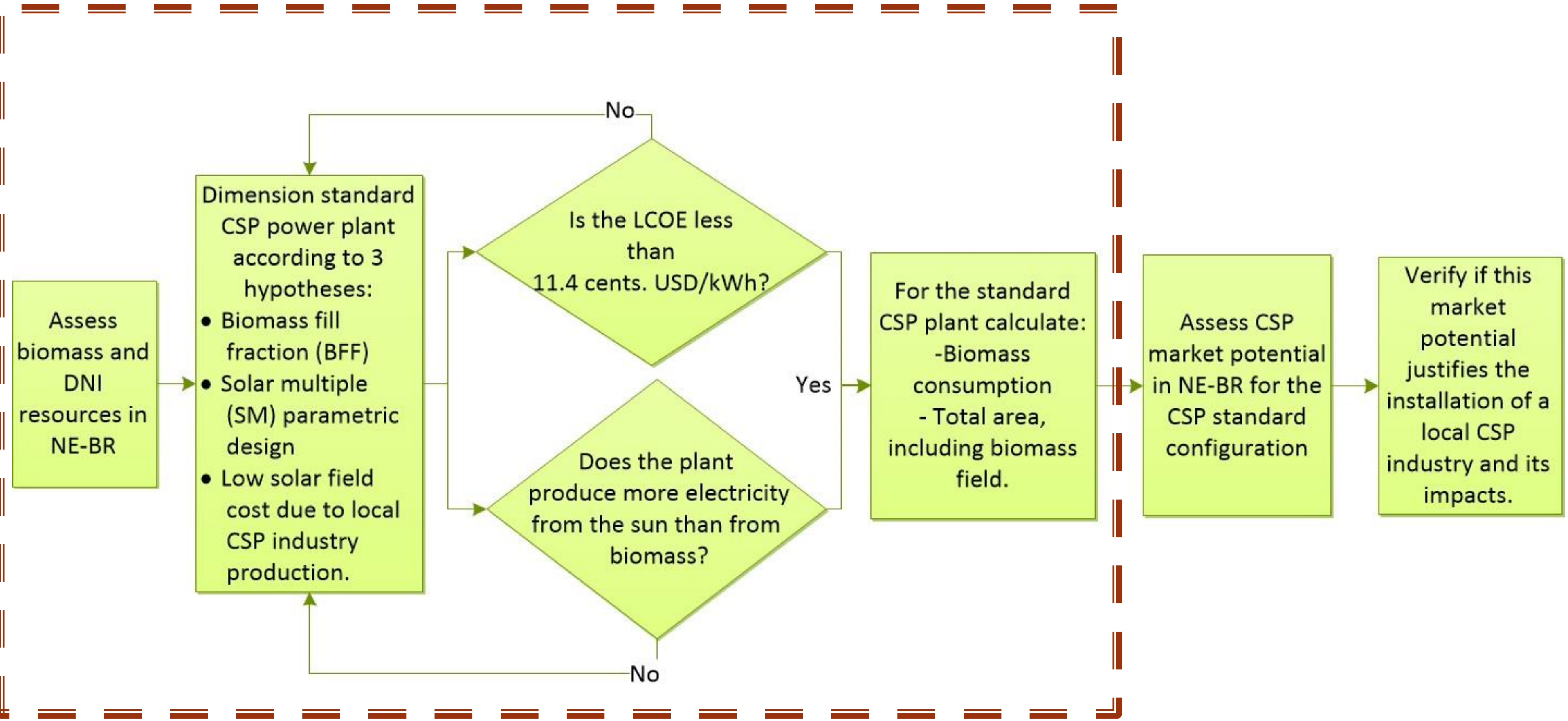
- Simulation of CSP plants hybridised with jurema-preta biomass by using primary data collected in the field at Fazenda União.

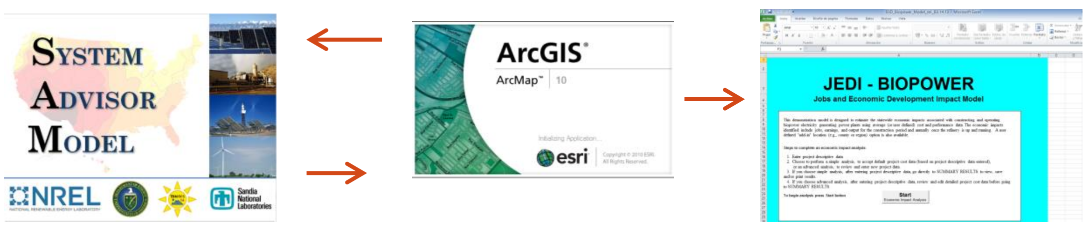
- Estimation of the market potential in the northeastern region of Brazil at a competitive LCOE, the direct and indirect job creation and the income creation associated with this industry.

- Personal communication experts from two rural properties and one CSP manufacturer company interested in the idea

- Our benchmarking price:

  - The Pernambuco state auction of December 2013 is an example of one auction where renewable power sources were contracted with high prices. In this auction, the upper price that opened the bid for an early-stage renewable energy source reached **11.4 cent. USD/kWh**.





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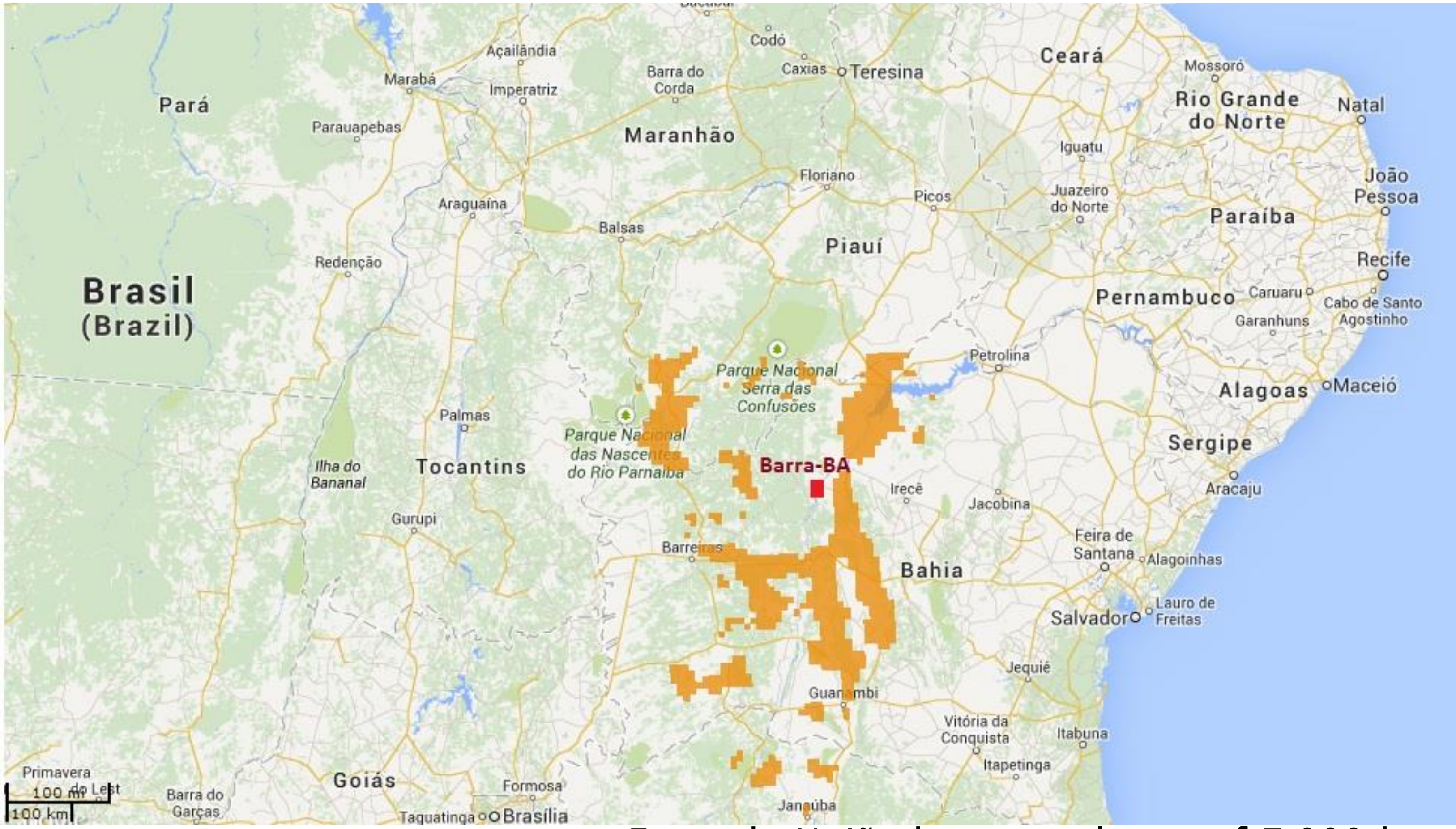
Study case at Fazenda União



Fazenda União has a total area of 7,000 hectares with an approximate volume of 539,000 m^3 of **jurema-preta** wood (485,000 tons)

Parameters for the simulations:

- In System Advisor Model (SAM)

Technical characteristics			Value
Solar Field	Solar field parameters	Solar multiple (SM)	To be calculated
		Normal direct irradiation at design	750 W/m^2
		Row spacing	15 m
	Heat transfer fluid (HTF)	Type	VP-1
		Inlet temperature	293 °C
		Outlet temperature	391 °C
		Minimum single loop flow rate	1 kg/s
		Maximum single loop flow rate	12 kg/s
		Header design minimum flow velocity	2 m/s
		Header design maximum flow velocity	3 m/s
		Solar field initial temperature	100 °C
	Collector orientation	Tilt	-13.27
		Azimuth	0
Collectors	Collector	Type	Solargenix
	Assembly	Number of collectors/receivers per row	8
Receivers	Receiver	Type	Schott PTR70
Power block	Power plant capacity	Net output at design (nameplate)	30 MWe
		Design gross output	33 MWe
		Parasitic losses	10%
	Power block design point	Thermodynamic cycle conversion efficiency	380%
		Back-up boiler operating pressure	100 bar
		Fossil back-up boiler efficiency	75%
		Water reposition fraction in the cycle	0.013
	Plant control	Assorted parameters	By default
		Turbine maximum operation capacity	1.05
	Cooling system	Condenser type	Evaporative
		Design room temperature	26.1 °C
		Water temp. diff. condenser outlet - inlet	10 °C
		Water temp. diff. cond. water inlet and wet bulb temp.	7 °C
		Min. condenser pressure	1.25 in Hg
Hybridisation	Hybridisation system	Power turbine output fraction	1.05
		Biomass fill fraction (BFF)	To be calculated

Source: NREL (2014), Soria (2011) and new assumptions by the authors.

Parameters			Value
Financing	General	Analysis period	30 years
		Inflation	0%
	Taxes and insurance	Actual discount rate	10%
		Federal tax	27%
		Insurance	0.5% of the cost of capital
	Loan parameters	Long term	20 years
		Loan rate	7.0% p.a.
		Debt fraction	80%
	Solution mode	Specific IRR target	Yes
	Actual IRR target	Minimum required IRR	10% p.a.
	Depreciation	Depreciation	5-year MACRS

Source: BNDES (2014), Schaeffer et al. (2012, 2014), Soria (2011) and new assumptions by the authors.

Costs		Value
Direct capital cost	Site improvements	30 USD/m²
	Solar field	215 USD/m²
	HTF	80 USD/m²
	Biomass hybridisation system	420 USD/kW$_e$
	Power block	830 USD/kW$_e$
	Balance of plant	110 USD/kW$_e$
	Contingency	20%
Indirect capital cost	EPC and ownership cost	11% of direct cost
	Land	0 USD/hectare
Operation and maintenance cost	Fixed cost per unit of capacity	65 USD/kW-year
	Variable cost per unit of power generation	5 USD/MWh
	Wood cost: *jurema-preta*	0.51 USD/MMBTU

Source: NREL (2014) and assumptions by the authors.

3. Results regarding the dimensions of the standard hybrid plant

LCOE (cents USD/kWh)[b]						
	BFF (%)					
SM	25	30	35	40	45	50
0.5	12.15	10.13	9.08	8.24	7.56	7.0
0.6	11.89	10.06	9.08	8.29	7.66	7.15
0.7	11.79	10.06	9.17	8.47	7.89	7.41
0.8	11.86	10.16	9.34	8.67	8.11	7.64
0.9	11.88	10.40	9.63	8.97	8.42	7.95
1.0	12.22	10.66	9.88	9.24	8.68	8.2
1.1	12.34	10.93	10.17	9.51	8.95	8.46
1.2	12.76	**11.31**	10.54	9.88	9.3	8.81
1.3	13.15	11.61	10.84	10.17	9.59	9.08
1.4	13.37	11.94	11.15	10.47	9.88	9.36
1.5	13.94	12.35	11.55	10.85	10.24	9.71

[b]Note: Orange cells indicate combinations of SM and BFF with an LCOE lower than 11.4 cents USD/kWh and a net annual electricity production mostly from the solar source.

Source: The authors.

3. Results regarding the dimensions of the standard hybrid plant

Participation of solar source in the annual electricity production (%)[c]						
	BFF (%)					
SM	25	30	35	40	45	50
0.9	n.a.	45.7	n.a.	n.a.	n.a.	n.a.
1.0	n.a.	49.0	45.4	n.a.	n.a.	n.a.
1.1	n.a.	51.6	48.0	n.a.	n.a.	n.a.
1.2	n.a.	**53.6**	49.9	46.8	n.a.	n.a.
1.3	n.a.	n.a.	51.3	48.1	n.a.	n.a.
1.4	n.a.	n.a.	52.3	49.1	n.a.	n.a.
1.5	n.a.	n.a.	n.a.	50.2	47.4	n.a.

[c]Note: n.a. (not available). These combinations were not simulated individually.

Source: The authors.

3. Results regarding the dimensions of the standard hybrid plant

Results of the individual simulation for SM=1.2 and BFF=30%

Simulation results	
Parameter	**Value**
Electricity production	139.3 GWh/year
* Solar contribution	53.6%
* *Jurema-preta* contribution	46.4%
Actual LCOE	11.31 cents USD/kWh
Capacity factor	51.4%
Annual water use	565 x 10^3 m^3
Total plant area	0.84 km^2
	83.7 hectare
Annual thermal energy produced in the boiler	185 GWh_{th}/year (666 TJ/year)

Source: The authors.

Total area by power plant, including the jurema-preta crop field: 51km^2

4. CSP into the integrated model MESSAGE-BRAZIL

MESSAGE-Brazil description

- 5 energy levels (+2 intermediate) :
  - Resources: 4 (non-renewable)
  - Primary energy: 8
  - Secondary energy: 18
  - Final energy: 20
  - Useful energy: 22 demands
- Around 300 energy conversion technologies
- Base year: 2010
- Temporal horizon: 2010-2050 in 5-year steps
  - Emissions: CO_2 emitted by the energy sector

Description –sectorial coverage

- Integrated model of energy sector (*bottom-up*):

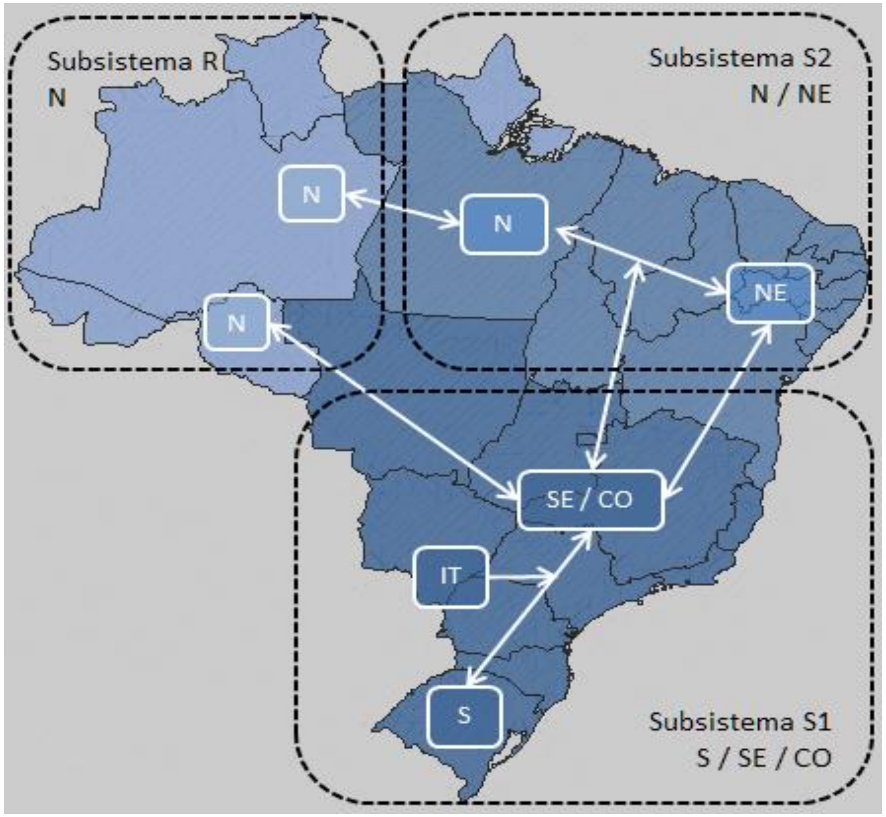
  Energy consumer sectors
  - 12 industries and agriculture
  - Buildings (residential and commercial)
  - Transport
  - Non energetic uses

  Energy conversion chain
  - Oil and gas
  - Refinery
  - Coal
  - Sugarcane bagasse
  - Biomass (wood and oleaginous)
  - Electricity

Regional coverage: Brazil - subsystems

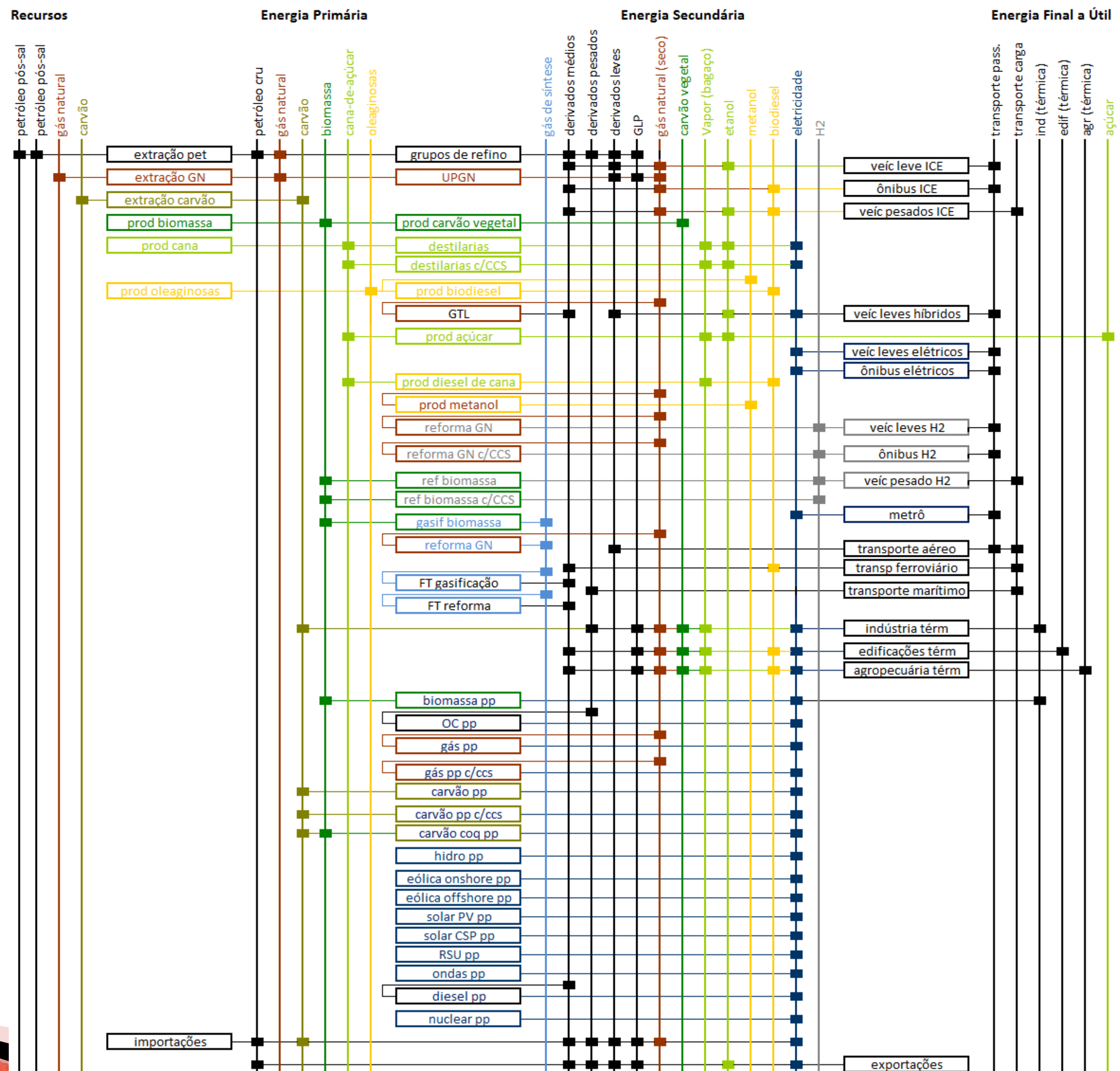
Fonte: IBGE

Fuente: ANEEL, SIGEL



Fuente: Soares Borba B., 2013

Simplified estructure of MESSAGE-Brazil



Fuente: Nogueira L., 2013

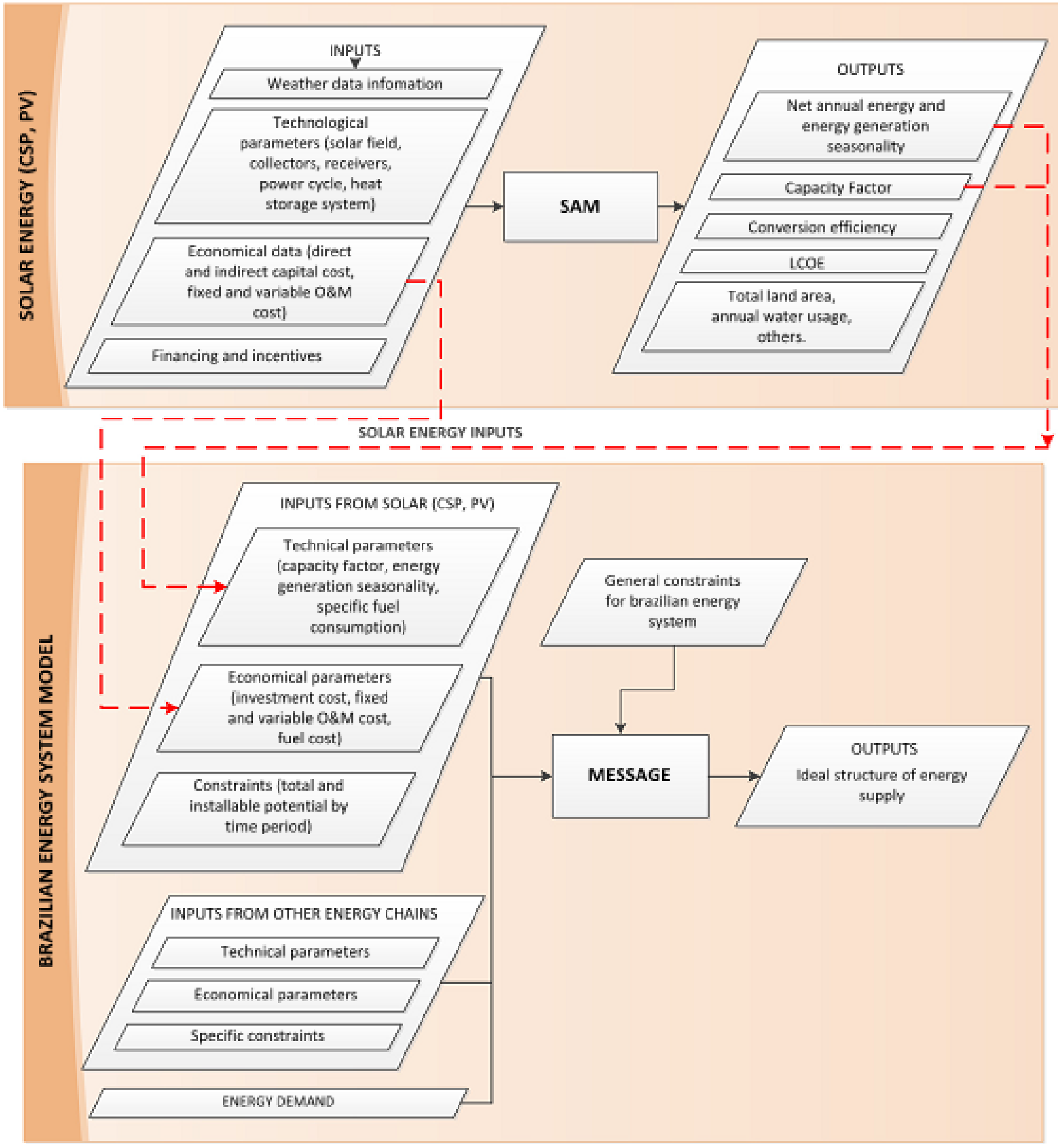


Fig. 2. Inputs and outputs of SAM and MESSAGE.

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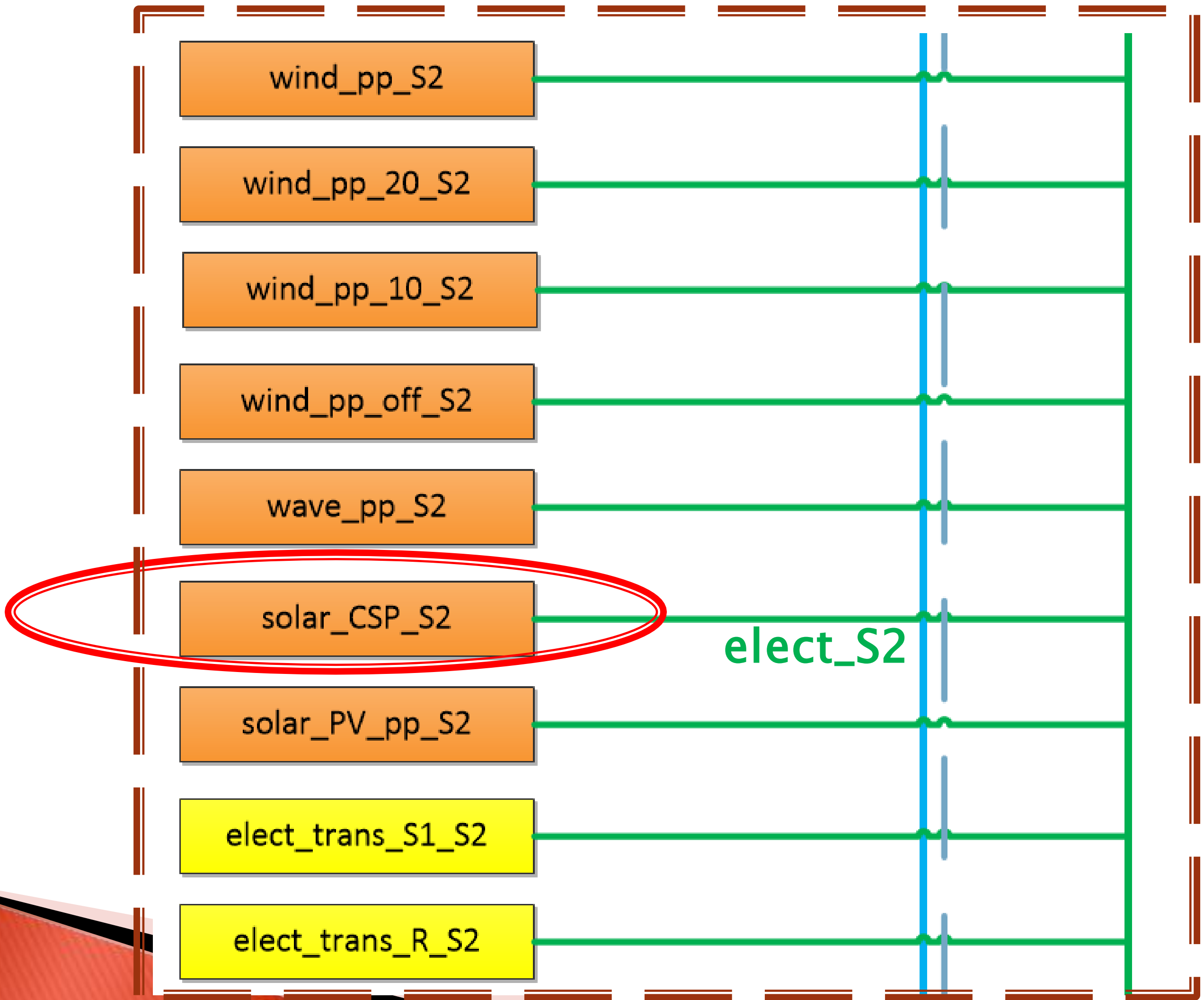
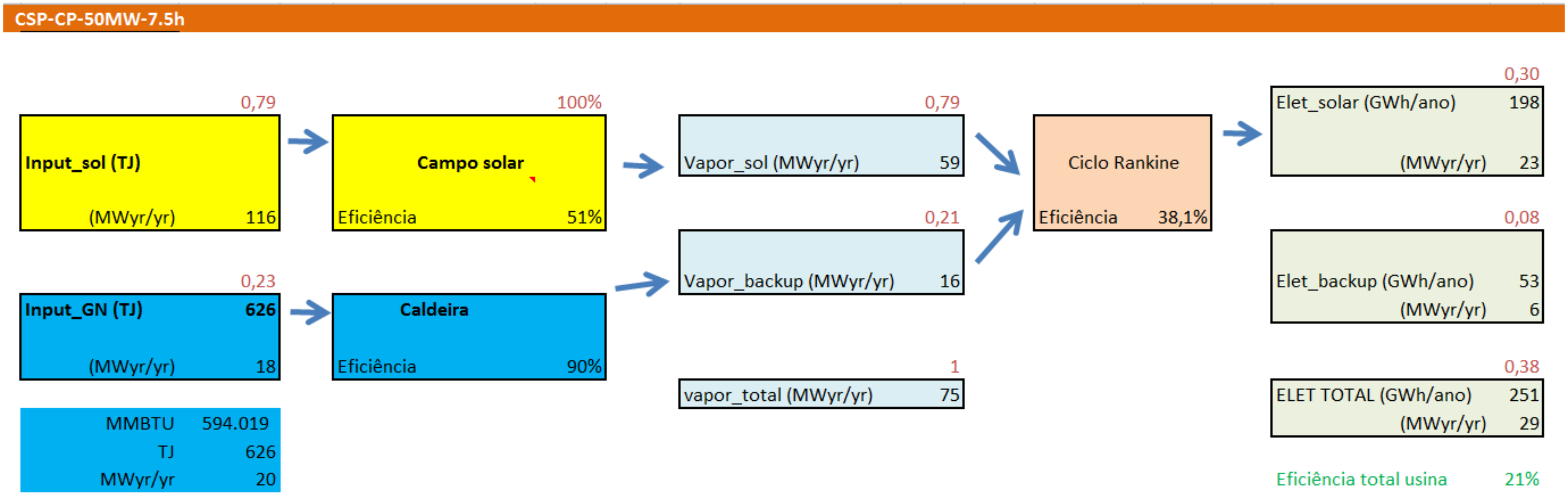
Representación simplificada de la tecnología CSP en MESSAGE-Brasil



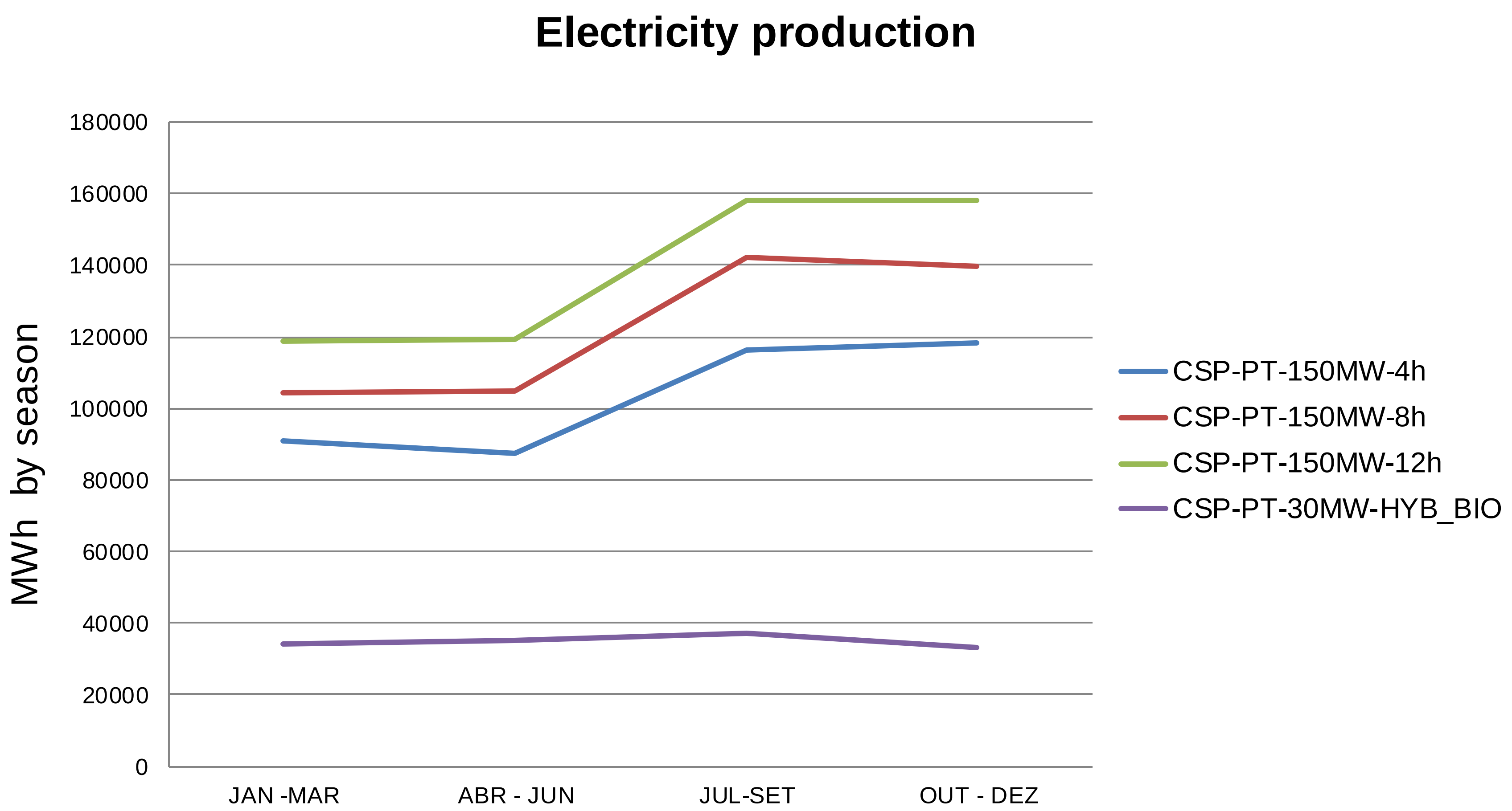
Fuente: Soria (2015)

Representación detallada de la tecnología CSP en MESSAGE-Brasil

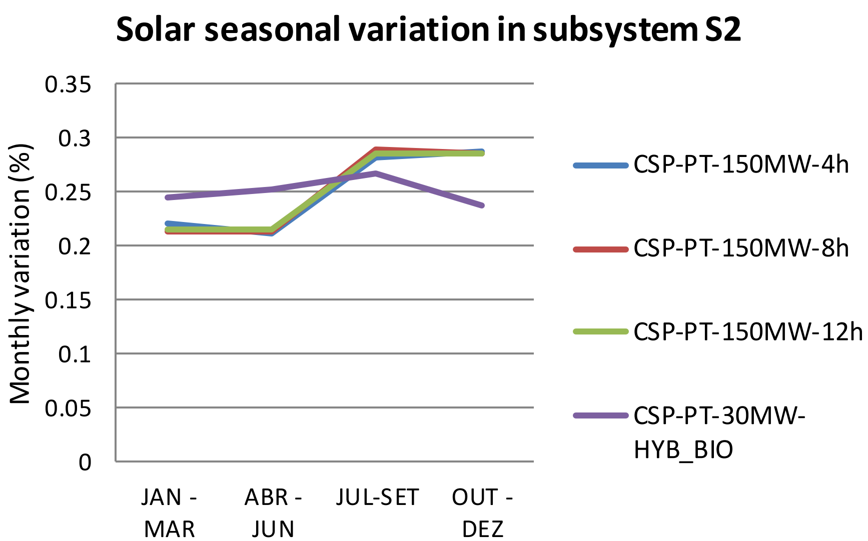


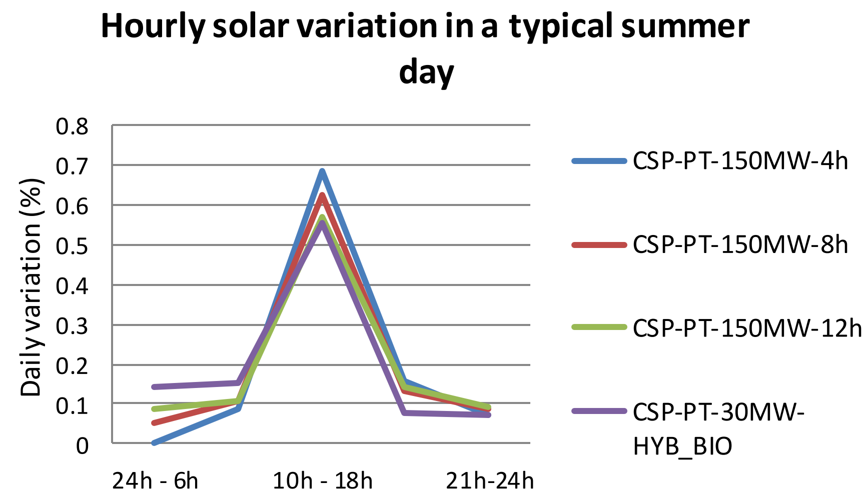
Fuente: Soria (2015)

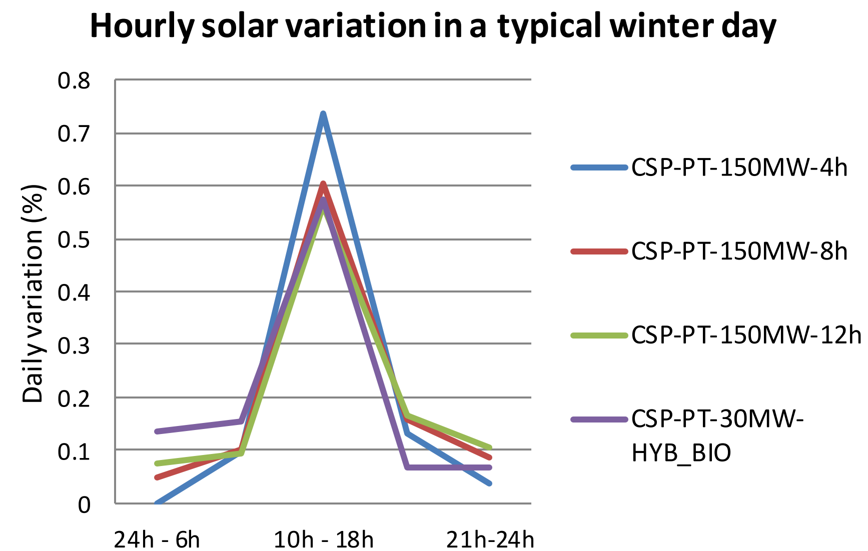
Operation of modeled CSP plants



Operation of modeled CSP plants







5. Final remarks

- Using a parametric analysis was determined that a CSP plant of 30MWe with SM of 1.2 and BFF of 30%, is possible having a solar plant that produces electricity with LCOE of 11.3 cents USD/kWh.
- In Brazil, the availability of biomass conveys competitive opportunities to CSP hybrid systems
- Brazil's CSP use would differ from the manner in which this technology is used elsewhere
- Establishment of CSP industry in Brazil is only possible having a long term planning and goals.
- The only viable option to decrease the solar field cost is the on-site production of CSP components. Possible in 2020 – 2025. Expected cost: 215 USD/m^2.

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- Thanks.